# A method to obtain correct standard uptake values in Pinnacle treatment planning system for target volume delineation

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## ABSTRACT

Standardized uptake value (SUV) is an advanced tool for quantitative tumor identification and metabolic target volume delineation (TVD) in diagnostic and therapeutic settings. It is thus important to establish a quality assured process to maintain the traceability of data correctly by positron emission tomography (PET) systems. Patient administration of $^{18}$fluoro-deoxy-glucose is increasingly delivered by automated infusion systems (AISs). Whenever AIS is used, its accuracy and traceability measurement need verification. In addition, it was observed that the unreproducible SUV displayed in PET and the treatment planning system (TPS) may cause grave concerns for radiation oncologists for TVD. This concern may complicate the correlation of TVD on PET and TPS and their clinical reporting. The SUV traceability was established from the PET system to AIS. Its accuracy was verified by cross-referencing to the reference dose calibrator traceable to a primary standard. The SUV values were converted in TPS using the in-house "clinical tool" to be identical as in PET, to allow radiation oncologists to use SUV confidently. The outcome of this study enables the clinical groups to rely on the correct SUV values displayed on the TPS and to improve the quality of care for patients in clinical procedures.

**Key words:** Functional imaging; metabolic target volume; positron emission tomography-computed tomography; standard uptake value; target volume delineation; treatment planning

## Introduction

The standardized uptake value (SUV) is a useful metric for quantitative analysis of positron emission tomography (PET) images, especially for tumor identification and cancer staging. SUV-based target volume delineation (TVD) is also shown to have significantly reduced interobserver variations.[1] Moreover, SUV can be used for "dose painting" or delivering differential doses within the target volume as it is highly correlated to the clonogenic cell density of the tumor.[2] Nevertheless, center-specific absolute SUV threshold based TVD and the variability in methodology across centers decrease the widely used SUV reliability.[3] Therefore, a standardized method to measure radioactivity traceable to primary standards is highly preferred; the assaying uncertainty of devices also influences the accuracy of the final SUV values in treatment planning system (TPS) and needs to be corrected. To address such issues, a multidisciplinary team of scientists and clinicians is required.[4]

SUV[5,6] by definition is a measurement of the uptake in a tumor normalized by radioactivity distributed within the whole volume (i.e., patient). It is an advanced tool for tumor identification and delineation based on the reference values associated with the tumor type of interest. Incorrect SUV has the potential to taint the integrity of clinical report

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as the multidisciplinary teams may find the quantitative values unreliable. The outcome may be an incongruous quantitative parameter to use for therapy and diagnosis. Tumor segmentation methods are employed to report a clinical outcome using metabolic target volume; however, it is recommended to always report with the maximum uptake value ($SUV_{max}$).[6-9]

SUV is calculated as shown in equation 1.

$$SUV = \frac{Act_{voi}\left(\frac{MBq}{ml}\right)}{Act_{admin}\left(MBq\right)/\text{Body weight}\left(kg\right)} \quad (1)$$

where $Act_{vol}$ is the radioactivity concentration in any volume of interest and $Act_{admin}$ is the total amount of radioactivity administered to the patient.

In this study, the lack of a traceable calibration system for $^{18}F$ was identified. This issue, however, is often neglected in diagnostic and therapy health-care centers despite using multiple clinical devices independent of each other. The traceability to reference instruments would then become a requirement for ensuring the accuracy of SUV for diagnostic and therapeutic procedures. "SUV traceable" is the SUV of an accurate measurement and traceable to primary standard for a structure at any given time by definition and shown as $SUV_{traceable,}$ in this study. Moreover, the traceability of the systems shall be maintained across the range of instruments when assaying or quantitatively calculating the $^{18}F$ activity directly, or indirectly. Thus, using automated infusion system (AIS) was deemed important, to be verified by cross-calibrating its internal dose calibrator to the reference dose calibrator. The traceable AIS will provide the correct SUV in our hospital. It is our standard procedure to inject patients with AIS; therefore, the SUV figures in our TPS need to be standardized and streamlined. The SUV value was verified by preliminary assessment of AIS, which was found to be non-traceable and unreliable. The findings were reported to the vendor when further service and upgrades on AIS proved to be beneficial where the AIS operation became optimized.

To make matters more challenging, it was further observed that Pinnacle™ (Philips Medical Systems, CA, USA) TPS was unable to interpret the SUV correctly from the Digital Imaging and Communications in Medicine (DICOM) images corresponding to a traceable PET.

Therefore, the objective of this study was to disseminate the SUV traceability of an established, calibrated PET instrumentation that is traceable to primary standards, and to develop a method to display correct SUV values in the TPS for accurate TVD.

## Materials and Methods

### *Dose calibrator calibration*

The PET/computed tomography (CT) scanner model used in this study was the Philips Gemini TF (Generation 3). It was calibrated and made traceable to National Institute of Standards and Technology (NIST) applying the methodology presented by Montgomery[9] and also employed concepts used in National Physical Laboratory[10] and Australian Standard Laboratory[11] works previously presented. All cross calibrations were verified using a NIST-traceable solid $^{68}Ge$ source as a $^{18}F$ surrogate. The traceability of the PET/CT to NIST and its relationship to clinical reporting in imaging and TPS is demonstrated in Figure 1, which highlights the traceability process to link the NIST properties of the dose calibrator which propagates its reliability directly to AIS, PET scanner's SUV, TPS, and clinical reporting of SUV.

### *Automated infusion systems calibration*

The AIS comprises of a vial pig, suction needle, dispensing line and coil, an injection line, a disposal line, an internal dose calibrator, and a saline bag.

AIS gets primed with saline for air removal from all lines before injection. It then samples a small amount of $^{18}F$ activity concentration knowing the total vial volume and its calibrated activity entered at dispensing. Then it measures the sample in its internal dose calibrator system. Once it passes the concentration test, it draws up the rest of the activity to top-up the required amount as prescribed. Next, it adds saline of approximately 35 ml for patient injection. Once it injects the patient with activity, it disposes of the remnant waste through the waste line.

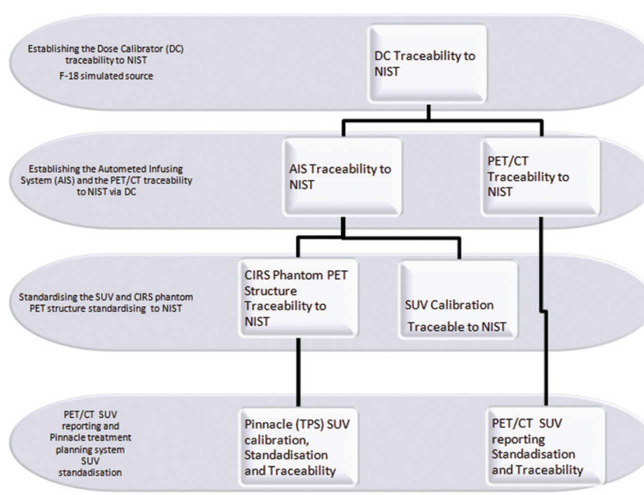


**Figure 1: Traceability of scanner's standardized uptake value and its relationship to clinical reporting and TPS**

The net activity injected by the AIS is therefore defined with the following equation.

$$A\ (\text{patient}) = (A[\text{sample}]) + A[\text{top.up}]) - A(\text{waste}) \quad (2)$$

where A(patient) represents the radioactivity administered to the patient, A(sample) is the tested concentration activity measured by internal dose calibrator, and A(top.up) is the amount required to make up the prescribed dose. A(waste) represents the amount disposed of in the leftover of the line of injection.

Observations were made to monitor the accuracy and consistency of the AIS at the time of commissioning and spanning over three annual quality assessments. It was noticed that there were significant errors in the prescribed and the received radioactivities to the patient (up to 20%). However, through several parts and software upgrades, the improvements were brought to within acceptable limits of 3% cross-referencing dose calibrators.

A consistency test was conducted for a 50 ml syringe, where it was used to collect the AIS's patient injections, to cross-calibrate the internal dose calibrator of the infusing system and the reference dose calibrator. The AIS was assessed using randomly selected radioactivities for injections in the range of 37–200 MBq of $^{18}$F.

The outcome was satisfactory as shown in Table 1. The percentage difference (PD%) between the prescribed and measured activity with the reference dose calibrator was within the advised cross-reference calibration of the reference and the field instrument traceability <3%.[10,11]

### PET/CT scanner calibration

The Philips SUV phantom was used according to manufacturer's instruction to calibrate the SUV baseline using SUV phantom, for clinical PET instrumentation normalization. A 1:1 ratio of the radioactivity in each CT slice volume was measured and compared to that of dose calibrator using the built-in software. The SUV calibration ensured that the PET/CT scanner has a 1:1 relationship to NIST traceable reference source; hence, the scanner itself is NIST traceable.[10,11] The phantom was filled using a manual injection method assayed in the reference dose calibrator.

### SUV cross-calibration

A Computerized Imaging Reference Systems (CIRS) Dynamic Thorax Phantom Model-008A was employed with PET inserts to use spherical structures of various volumes viz. 0.5, 2.0, and 8.0 ml filled with the known concentration of fluoro-deoxy-glucose. The change in CIRS phantom use was to alter the medium from SUV assessment in PET/CT. The CIRS phantom was scanned using a clinical PET/CT standard body protocol. All the spherical structures were identified in PET/CT images and the SUVs were calculated. The calculated values were identical to that of measured SUVs using the image processing tools available in the PET/CT. A circular region of interest was created for each spherical structure in PET using CT as a guide. These image files were transferred to Pinnacle TPS, for further image processing and target delineation. It was however observed that Pinnacle employs radioactivity concentration but not the actual SUVs as shown on PET/CT. A scripting tool was developed in-house, to overcome this problem. The relevant DICOM tags for the interpretation of SUV are given in references.[12-15]

The Pinnacle TPS displays the pixel values or activity concentration calculated from the stored pixel values and its associated DICOM tags as shown in equation 3.

$$U = (m \times \text{SV} + b) \quad (3)$$

where $U$ is the activity concentration of each voxel, m is the rescale slope, SV is the stored pixel value, and $b$ is

**Table 1: Comparison of prescribed activity, activity displayed as delivered and activity measured**

| *Prescribed activity (MBq)* | *Activity displayed as delivered (MBq)* | *PD% prescribed and displayed* | *Activity measured (MBq)* | *PD% displayed and measured (%)* |
|---|---|---|---|---|
| 108 | 108.8 | −0.74 | 105.11 | 2.27 |
| 200 | 199.3 | 0.35 | 198.0 | 0.02 |
| 200 | 197.3 | 1.35 | 195.0 | 0.54 |
| 110 | 108.4 | 1.45 | 108.6 | −0.18 |
| 40 | 38.5 | 3.75 | 38.0 | 1.30 |
| 37 | 36.8 | 0.54 | 36.9 | −0.27 |
| 50 | 50.0 | 0.00 | 49.5 | 1.00 |
| 39 | 39.0 | 0.00 | 39.1 | −0.26 |
| 37 | 36.9 | 0.27 | 37.2 | −0.81 |
| 37 | 36.9 | 0.27 | 36.9 | 0.00 |
| 40 | 40.0 | 0.00 | 40.0 | 0.00 |

PD%: Percentage difference

the rescale intercept as defined in the DICOM standard. The value of $b$ is set to 0 and $m$ to 1 for the PET images in Pinnacle. Thus, it is possible to retrieve the actual SUV values by modifying the rescale slope "$m$" in the Pinnacle TPS. This process is shown in Figure 2.

## Results

The results for AIS cross-calibration with reference dose calibrator is shown in Table 1 which displays the activity dialed on AIS, as prescribed to a patient, and displayed on printed AIS injection label, after delivery. It also shows AIS radioactivity measured by reference dose calibrator to record comparisons in PD%, for displayed and measured activities.

The SUV figures in PET and Pinnacle consoles from randomly selected patients were recorded, and their constant median ratio of 5.23 was obtained and given in Table 2 before applying the "clinical tool" corrections. This value corresponds to Activity Concentration Scale Factor 5.222854, given in PET phantom studies listed in Table 3.

The combined uncertainty of fluorine-18-deoxyglucose activity injected into patients using the AIS is provided in Table 4. Quality performance monitoring period used records from July 27, 2013, to July 27, 2014; absolute difference of assaying a traceable $^{18}F$ simulated source to NIST was demonstrated in this section.

The detailed information regarding the DICOM tags used in Pinnacle and their values in DICOM header for each PET insert employed in the CIRS phantom as radiotherapy structure is provided in Table 3. These tags are further explained in Table 5, explaining Rescale Unit, Rescale Slope, SUV Scale Factor and Activity Concentration Scale Factor.

A flowchart was developed to manage the Python scripting demonstrated in Figure 2, after studying the Pinnacle DICOM conformance and how the SUV is calculated in PET console and the requirement as how to interpret the PET SUV in Pinnacle. The logic of using a plugin script in Python was to enable the steps required to calculate the correct SUV in Pinnacle that is calibrated and traceable to PET.

NIST traceability of dose calibrator performance with respect to the NIST $^{18}F$ simulated reference source is shown in a distribution chart in Figure 3, where the precision and frequency of dose calibrator performance is highlighted.

PET-fused images of CIRS Phantom with 8 mm PET insert were viewed in PET and Pinnacle consoles. After running the script, the Pinnacle SUV traceability to PET images was found to be identical. They both now represent the same $SUV_{max}$. The $SUV_{traceable}$ was thus verified as shown in Figure 4.

**Table 2: Comparison of PET console $SUV_{max}$ and TPS console $SUV_{max}$ and their ratio**

| *Patient number* | *Volume (mm³)* | *PET console $SUV_{max}$* | *TPS console $SUV_{max}$* | *Ratio* |
|---|---|---|---|---|
| 1 | 29.25 | 14 | 73.24 | 5.23 |
| 2 | 71.94 | 6.7 | 34.91 | 5.21 |
| 3 | 21,312.50 | 10.5 | 55.00 | 5.24 |
| 4 | 48,159.30 | 28.5 | 148.95 | 5.23 |
| 5 | 7679.88 | 28.2 | 147.32 | 5.22 |

$SUV_{max}$: Maximum standardized uptake value, PET: Positron emission tomography, TPS: Treatment planning system

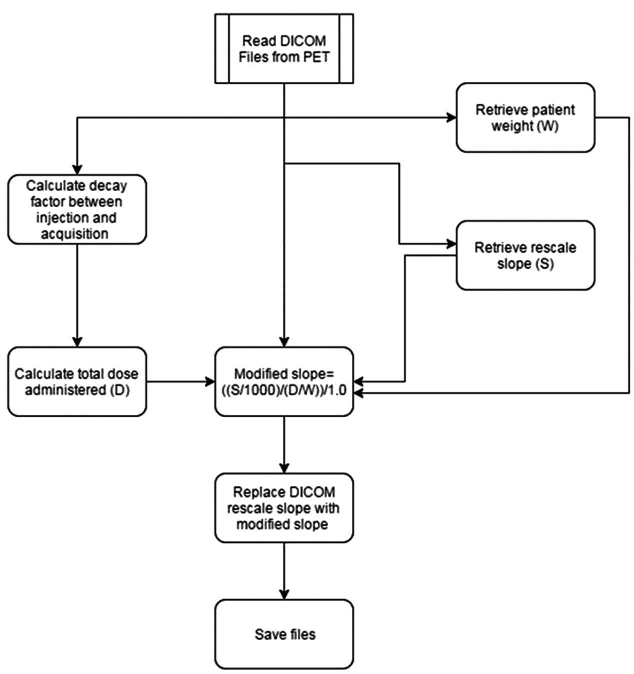


**Figure 2: The "clinical tool" flowchart used to develop the scripting for Pinnacle**

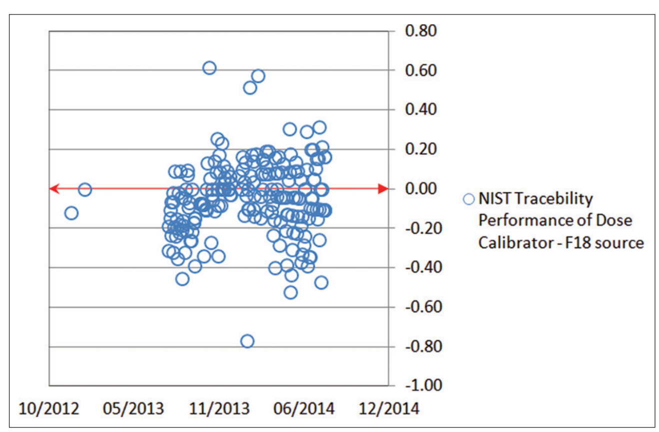


**Figure 3: Quality control of reference dose calibrator using the NIST-traceable solid $^{68}Ge$ source as a $^{18}F$ surrogate**

**Table 3: DICOM tags and values for the three different structures**

| *Sphere size (ml)* | *Corresponding DICOM tags* | | | |
|---|---|---|---|---|
| | 0054,1001 | 0028,1053 | 7053,1000 | 7053,1009 |
| | | *DICOM values* | | |
| 0.5 | BQML | 5.222854 | 0.392451 | 5.222854 |
| 2.0 | BQML | 5.222854 | 0.394207 | 5.222854 |
| 8.0 | BQML | 5.222854 | 1.824347 | 5.222854 |

DICOM: Digital Imaging and Communications in Medicine, BQML: Becquerel per milli litre

**Table 4: Combined uncertainty table for $^{18}$F injected to patients using automated infusion systems**

| *Influence quantity* | *Type* | *Distribution* | *Expanded uncertainty* | *Unit* | *Coverage factor* |
|---|---|---|---|---|---|
| Absolute difference between the delivered and actual activity | B | Normal | 1.00 | % | 1 |
| Calibration of the ionization chamber | B | Normal | 0.50 | % | 1 |
| Measurement precision of the ionization chamber | A | Normal | 0.22 | % | 1 |
| Combined uncertainty | | | 1.14 | % | 1 |

**Table 5: DICOM definitions used in Pinnacle used in equation 3**

| *Pinnacle DICOM definitions* | *DICOM tags* |
|---|---|
| Rescale slope | 0028,1053 |
| Rescale intercept | 0028,1052 |
| SUV scale factor | 7053,1000 |
| Activity Concentration Scale Factor | 7053,1009 |
| Rescale Unit | 0054,1001 |

DICOM: Digital Imaging and Communications in Medicine, SUV: Standardized uptake value

## Discussion

This study identified two significant points. It revealed the importance of establishing and maintaining the measurement traceability of the radioactivity assaying instruments (e.g., dose calibrator and AIS where applicable) whose accuracy would have a direct impact in the calibration of the PET/CT console and the quantitative values used for diagnostic and treatment planning purposes. Secondly, it has highlighted the inadvertent misinterpretation of SUV values by the planning system Pinnacle and proposed a method for correction.

SUV is often assumed by clinicians to be a standardized quantitative value, used clinically in diagnostic and therapeutic aspects of patient management. However, it was found that health centers may be unaware of the traceability requirements, and their impacts on clinical outcomes.

In this work, the need to have a national standardized SUV approach was also recognized, i.e., a national reference $^{18}$F simulated source to be selected by Activity Standard Laboratory of Australian Nuclear Science and Technology Organisation and circulated to all PET centers to form $^{18}$F traceability. A national approach will assure a calibrated standardized SUV to be employed in Australia.

Further discussions on the possibility of vendor dependency of this study highlighted that other untested TPS platforms may not be reliable. Our local experience shows that the TPS Pinnacle had incorrect interpretations of PET SUV data generated from a Philips PET/CT console. Given that various PET systems may determine SUV in a different manner (e.g., using private DICOM tags) and hence the interpretation of that would result in nonmatching SUV in TPS, we believe it is worthwhile to consider assessment of different vendors' combinations of PET/CT console and TPS similar to this study.

Our physicians have already expressed interest in standardizing and using our methodology for future clinical effectiveness to liaise with two other health centers.

Their interest is due to improved clinical efficiency and reliability in $SUV_{max}$ figures. Work is already under progress for developing functional imaging based TVD.

## Conclusions

The quantitative analysis of results based on $SUV_{max}$ is identical in both Pinnacle and PET processing terminals. A method to accurately define target volumes based on SUV has been implemented in Pinnacle TPS that is traceable to images obtained on the PET console. Overall,

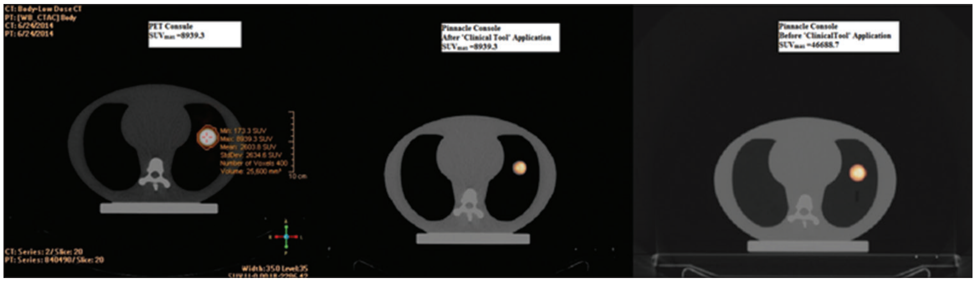

**Figure 4: Before applying the "clinical tool" in TPS, $SUV_{max}$ was 46688.7 (right). After applying the "clinical tool" in TPS, $SUV_{max}$ was 8939.3 (middle) which is equivalent to the figure displayed in the PET console (left)**

it was demonstrated that the clinical effectiveness of our practice in diagnostic imaging and radiation oncology is considerably optimized, and patients are benefiting from a consistent, quantitative analysis of their disease prognosis, treatment, and follow-ups.[6-8]


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Nil.


### *Conflicts of interest*

There are no conflicts of interest.

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